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RANGE-GATED MOVING TARGET INDICATOR WITH DIGITAL FILTERS

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Range-gated and filtered moving target indicators offer improved reliability and performance as compared to systems employing delay-line cancelers. The application of digital filters in a range-gated MTI system has been demonstrated.

RANGE-GATED MOVING TARGET INDICATOR WITH DIGITAL FILTERS

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Abstract

Range-gated and filtered moving target indicators offer improved reliability and performance as compared to systems employing delay-line cancelers. The application of digital filters in a range-gated MTI system has been demonstrated.

INTRODUCTION

One of the challenging problems presented to the radar designer is the problem of detecting weak returns from relatively small moving targets such as low flying aircraft, land vehicles, or personnel, in the presence of relatively strong fixed target return or clutter. The separation may be accomplished by taking advantage of the fact that the echo spectrum associated with moving targets is shifted in frequency by the doppler shift, f_d,

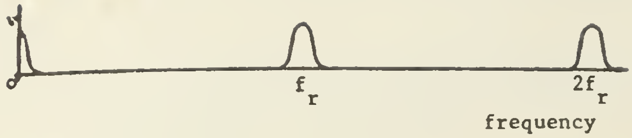
$$f_d = \frac{2v_r f_o}{c} \qquad (1)$$

where v_r is the relative radial velocity of the moving target, f_o is the carrier frequency and c is the velocity of propagation. There is no frequency shift for fixed targets.

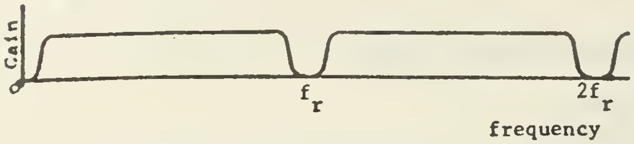
In moving target indicator (MTI) radars short, widely spaced pulses are transmitted as in conventional pulse radars, but with the difference that these pulses are phase coherent. In the receiver the echo spectrum is translated to video frequencies. The clutter spectrum in the video amplifier is concentrated around zero frequency and multiples of the pulse repetition frequency, f_r, as shown in Figure 1(a). The clutter spectrum consists of a number of bands since the signal return is amplitude modulated by rotation of the radar antenna and since there frequently is incidental motion associated with clutter scatterers such as vegetation and ocean waves. The width of these clutter bands is, then, a function of antenna parameters including rotation rate, and of the nature of the clutter and the wind velocity.

Associated with moving targets are video frequency bands at the doppler frequency, f_d and at $nf_r \pm f_d$ where, n is any integer. Generally there are pairs of bands between successive multiples of f_r for each moving target, the second one being due to a folding of the spectrum about the carrier frequency in the process of frequency translation to zero frequency. Another viewpoint is that the pairs of frequency bands are due to sampling of the doppler-shifted target echo at the pulse repetition frequency.

The ideal clutter elimination filter is a band-elimination comb filter as indicated in Figure 1(b). The width of the rejection notches should be matched to the width of the clutter bands, and



(a) MTI video clutter spectrum



(b) Frequency response of ideal MTI filter

Figure 1. Clutter spectrum and ideal MTI clutter rejection filter

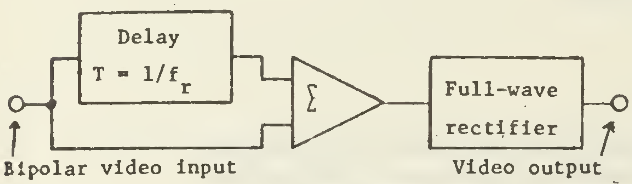


Figure 2. Delay-line MTI canceler block diagram

ideally should be adjustable to conform to changing conditions. Gain should be constant between the rejection notches.

THE DELAY-LINE CANCELER

The traditional MTI filter is the delay-line canceler shown in block diagram form in Figure 2. The frequency response characteristic can be shown to be in the form $|\sin \pi f/f_r|$ which is plotted in Figure 3. This characteristic is not optimum in two respects. The rejection notches exhibit high attenuation only in an extremely narrow band, and the gain is not constant between rejection notches.

Delay-line cancelers suffer from other shortcomings. The delay-line itself has very high attenuation, and this signal loss must be made up in a high-gain amplifier. The pulse repetition period must be very closely matched to the delay, and this delay varies considerably with changes in temperature. Because of these factors the complete delay-line canceler is quite complicated, and failure of any one of a large number of components can make it inoperative.

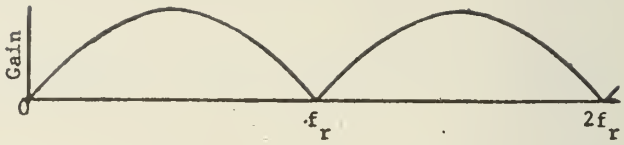


Figure 3. Delay-line canceler frequency response

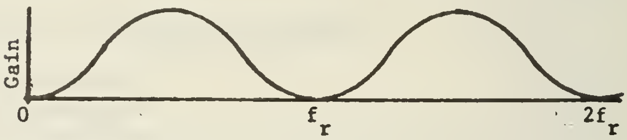


Figure 4. Double delay-line canceler frequency response

The width of the rejection notches can be increased resulting in improved clutter rejection by cascading two delay-line cancelers. The resulting frequency-response characteristic, Figure 4, is still far from ideal, however. Moreover the system complexity of the resulting system unfortunately is prohibitive.

MTI BY RANGE GATES AND FILTERS

Figure 5 shows a block diagram of an MTI canceler employing range gates and filters. A large number of parallel channels may be used corresponding to a number of adjacent range intervals that are to be examined for the presence of targets. Each channel contains the information for a particular small range interval. The input range gate of each channel samples the coherent video signal at a time following transmission of a pulse corresponding to the range. Each channel therefore samples the video signal at the pulse repetition frequency, and frequency information in each channel is limited to $f_r/2$. This is adequate since each moving target has an associated video component between zero frequency and $f_r/2$. The hold feature increases the relative amplitude of the signal component in the band between zero frequency and $f_r/2$. The sampling process then essentially reduces the signal and clutter spectrum to a region between zero frequency and $f_r/2$.

Following the sample-and-hold circuit is a bandpass filter having the characteristic shown in Figure 6. This filter rejects the remainder of the clutter spectrum, but passes the lowest

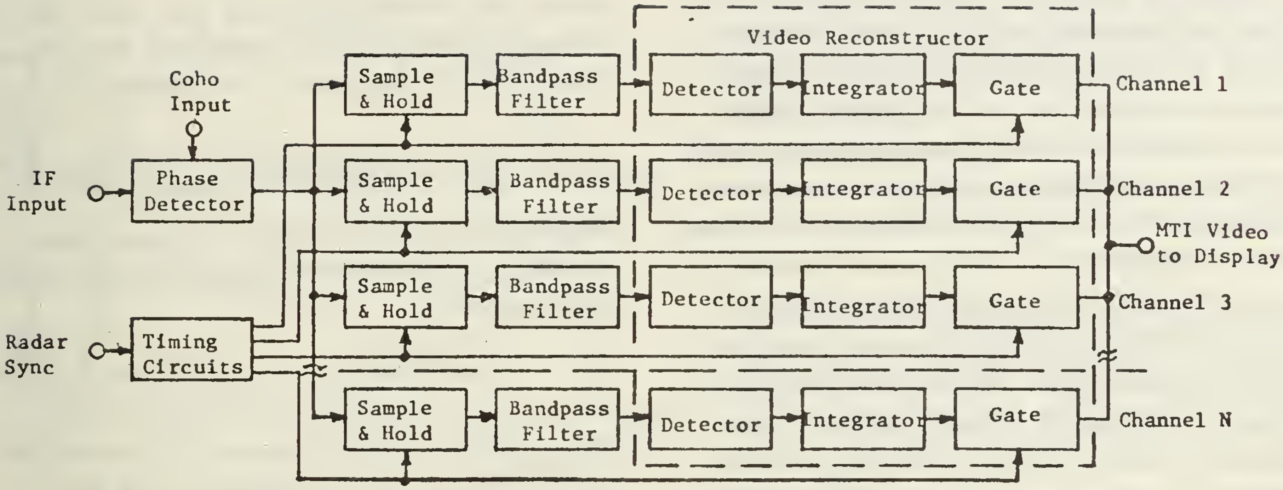


Figure 5. MTI by range gates and filters, block diagram

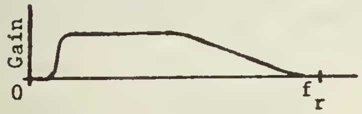


Figure 6. Bandpass filter for range-gated MTI

frequency band associated with those moving targets not moving at a blind speed, any speed where the doppler shift is a multiple of f_r.

The signal from the filter is detected, integrated with a time constant compatible with the look time (the time the target is illuminated by the radar), and then applied to a gate which is gated by the same pulse applied to the sample-and-hold circuit at the input of the channel. Clutter is largely eliminated by the filter, but if a moving target signal is present within the filter passband, an output pulse is formed at a time corresponding to the target range. Pulses from the several channels are combined to form an MTI video signal which is applied to the radar indicator.

A range-gate-and-filter MTI system provides superior performance as compared to a single or double delay-line canceler in two important respects. The filter characterists are much closer to the ideal so that greater cancellation of clutter is obtained, and gain is more nearly independent of the velocity of a moving target. The system is also much more reliable since a number of channels are placed in parallel. Failure of a component will disable only one channel reducing the system sensitivity at that range. A moving target does not remain at constant range, so the probability of detecting a given moving target is only slightly impaired. With modern integrated-circuit techniques overall system complexity, cost, physical size, and power consumption can stay within reasonable limits.

FILTER SELECTION

We have seen that the bandpass clutter rejection filter for a range-gated MTI system should provide high attenuation from zero frequency to the highest frequency where objectionable clutter components occur, typically about 50Hz for a radar operating at 1200 MHz. The cutoff frequency preferably should be adjustable. Attenuation should be low from this frequency to $f_r/2$, and should be high in the vicinity of f_r and at higher frequencies.

Although LC filters can be built having the desired performance, they are physically quite large and heavy. Active RC filters are a better choice, and such filters with adjustable cutoff frequency for range gated MTI systems have been built [2].

Another filter type that shows considerable promise for the range-gated MTI is the analog

cancellation filter[3]. Such filters combine delayed and undelayed samples of the signal to obtain the desired frequency response. Sample-and-hold circuits are used for signal storage. Filter shape and cut-off frequency can be varied by changing gain factors in feed-back and feed-forward paths. The chief drawback of this filter type is complexity.

Digital filters have several attractive characteristics for use in range-gated MTI systems. Filter characteristics can be varied by software changes. Although an extensive amount of hardware is required to implement a large number of channels, cost and size of digital hardware has been minimized through the use of large-scale integration, and reliability is high. Overall filter system complexity can be minimized by sharing of hardware between channels. One analog-to-digital and one digital-to-analog converter, for example, can be shared between many channels. A disadvantage of the digital filter is quantization noise and limit cycles which can have an effect on the overall system signal-to-noise ratio [4], but this effect should be small compared to the gain obtained in improved characteristics as compared to the delay-line canceler.

DIGITAL IMPLEMENTATION

To verify the postulated performance of range-gated MTI system with a digital filter, a single channel was constructed and tested on the AN/UPS-1 radar at the Naval Postgraduate School [5]. Its delay-line canceler was used for comparison of MTI performance. Since the radar and the XDS-9300 computer used in the implementation are separated by a considerable distance, the sampled video signal was recorded on magnetic tape, and the tape was later played into a D to A converter for processing at the computer. Since sampling was at the 800 Hz pulse repetition frequency of the radar, it was possible to use a narrow-band instrumentation tape recorder.

A third-order Chebyshev-type filter was selected for the implementation. With this implementation the computer was able to process the 800 Hz input pulses from a single channel in real time. The frequency-domain transfer function of the low-pass filter with 0.5 dB ripple in the passband is

$$H(s) = \frac{1}{s^3+1.2529s^2+1.5349s+0.7157} \qquad (2)$$

The bandpass filter is derived by mapping this transfer function into the z plane with the bilinear transform

$$S = \Omega\,\frac{z+1}{z-1} \text{ where } \Omega = \tan\frac{\pi f_c}{f_r} = \tan\frac{\phi}{2} \qquad (3)$$

where f_c is the corner frequency. By controlling ϕ, the passband can be controlled. With $\phi = 30°$ and $f_r = 800$ Hz, the passband extends from 67 to 733 Hz. Increasing ϕ to 60° changes the passband to 133 to 667 Hz. The corresponding equations for H(z) are

$$H(z) = \frac{0.805(z-1)^3}{z^3-1.94z^2+1.37z-0.30} \quad \phi=30° \qquad (4)$$

$$H(z) = \frac{0.452(z-1)^3}{z^3-0.923z^2+0.643z-0.025} \quad \phi=60° \qquad (5)$$

The corresponding transfer functions are plotted in Figure 7.

PERFORMANCE EVALUATION

The evaluation of the digital moving-target indicator was done by comparing its performance with that of the single delay-line canceler of the AN/UPS-1 radar. The two parameters which were measured and formed the basis for a comparison were minimum discernible signal and subclutter visibility.

The minimum discernible signal (MDS) is the weakest echo that the radar receiver is able to detect and process. It is limited by both receiver and atmospheric noise that occurs within the same part of the frequency spectrum as does the echo signal.

The subclutter visibility (SCV) is a measure of the moving-target indicator's ability to detect moving-target signals superimposed on clutter signals. It is defined as the gain in signal-to-clutter power ratio produced by the MTI. For

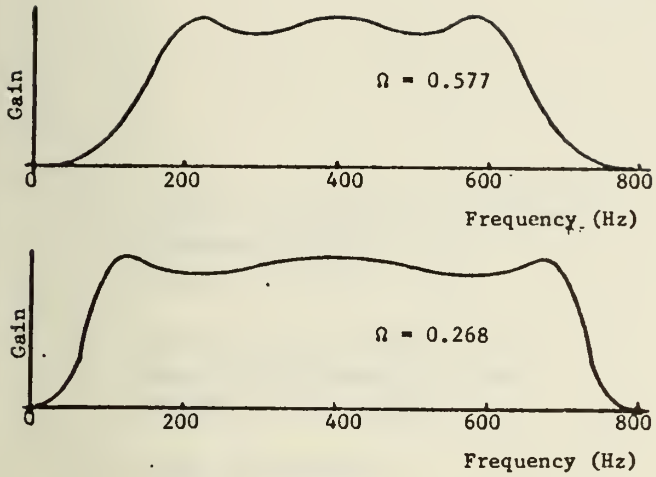


Figure 7. Digital filter transfer characteristics.

example, a SCV of 20 dB implies that a moving target can be detected in the presence of clutter even though the clutter echo power is 100 times the target echo powers.

By injecting the equivalent of a moving target from a signal generator into a directional coupler located in the wave-guide of the radar, accurate measurements could be made of the minimum discernible signal and subclutter visibility. For a given input signal, the output of the AN/UPS-1 radar's delay-line canceler could be observed on its own A-scope and plan-position indicator and on an external oscilloscope while the output of the sample-and-hold circuit, the only element of the digital MTI system in the radar lab, was recorded on magnetic tape.

The recorder had seven channels and was used in the evaluation phase in the following manner. A recording of the output of the sample-and-hold circuit for a given input signal power was made on one channel while noting the level of output of the delay-line canceler on the oscilloscope. This process was then repeated six times on the other channels, each time with a discrete reduction in input signal power, before the recorder was moved to the computer lab for the remaining signal processing.

In the computer laboratory the several signals were processed in turn until no discernible signal was noted on the display oscilloscope. This constituted the MDS of the digital MTI for comparison with the MDS obtained with the radar's delay-line canceler.

The measurement of subclutter visibility was done with the radar transmitter operating and the antenna stopped in a direction of much ground clutter. A coherent moving target signal was simulated by super-imposing the output of an audio signal generator on the clutter at the input to the sample-and-hold circuit. In the delay-line canceler the measurement was made by moving the pulse signal from a signal generator to the same area of high clutter.

RESULTS

The minimum discernible signal (MDS) was measured in the absence of clutter. For the digital MTI the MDS was the same as that measured for the normal non MTI video of the radar, -105 dBm. The MDS of the delay-line canceler was -96 dBm. Thus the digital MTI has 9 dB greater sensitivity than the delay-line canceler due primarily to improved frequency response characteristics and lower internal noise.

The subclutter visibility was measured in the manner previously described. The SCV of the delay-line canceler was 21 dB while that of the digital filter was 25dB, a 4 dB improvement.

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